NUTRIENT CYCLING

Year-Round Soil Nutrient Dynamics from Broiler Litter Application to Three Bermudagrass Cultivars

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ABSTRACT

Understanding manure nutrient dynamics in soil with any crop is an important management practice for farmers and producers to document accountability and to use manure resources optimally. A field experiment was conducted to quantify input, output, and the year-round major plant nutrient dynamics in a fine sandy loam soil supplied with 15.75 Mg ha^{-1} yr^{-1} broiler litter. Soil samples were collected from pre-established plots of common bermudagrass [*Cynodon dactylon* (L.) Pers.] and hybrid bermudagrass cultivars Coastal and Tifton 85 for nutrient analysis. Coastal and Tifton 85 produced significantly greater annual dry matter yield (16 948 and 18 772 kg ha^{-1}) than common bermudagrass (11 238 kg ha^{-1}). Tifton 85 was most efficient and removed 344, 58, and 472 kg ha^{-1} N, P, and K, respectively. The removal efficiency of these nutrients for Tifton 85 was 73, 18, and 114%, respectively. Soil pH varied from 6.0 to 6.6 until it decreased unexpectedly to 5.6 by the end of 2001. Total soil C increased from 11.4 g kg^{-1} to 17.9 g kg^{-1} by the end of the second year. At all sampling dates, the NO_3–N concentration was greater than NH_4–N while total N decreased during the maximum uptake in late spring and summer. Both total P and Mehlich-3 extractable P concentrations increased mainly in the 5- to 10-cm depth, indicating slight leaching of P. Results indicated that top yield from hybrid bermudagrass cultivars is possible with broiler litter as a sole fertilizer source. However, considerable nutrient imbalances in soil may occur in the long term if improper litter rates are used.

Repeated applications of manure to crop and pasture lands may cause a significant buildup of nutrients and salts in soils; particularly in poultry producing regions of the south-central and southeastern USA (Eghball and Power, 1999; Simrad et al., 1995; Carpenter, 1992). Most areas with intensive domestic livestock and pasture systems have begun monitoring farm import and export of elemental nutrients (Van Horn et al., 1996). For a farm to be sustainable, its nutrient budget should balanced, at least after soil background nutrient reserves are brought up to desired levels for sustainable production. If a net nutrient loss occurs over a long time, the soil will become depleted. On the other hand, if there is excess of nutrients, potential for leaching and surface runoff will become greater. Environmentally, N and P are considered the most critical manure nutrients with regard to buildup in soil, surface runoff, and loss to the atmosphere (Sharpley et al., 1993; Pierson et al., 2001; Sharpley, 2003).

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Production costs for commercial fertilizers continue to increase because of demand. For many years, animal manure waste has been more economical than commercial fertilizers for plant nutrients. Manure nutrients are potentially recyclable through plants, which avoid losses of nutrients to water or the atmosphere (Simpson, 1991; Wood, 1992; Edwards, 1996). Generally, manure application rates are based on crop N requirement rather than P requirement. This mismanagement will always occur since the manure N/P ratios are lower than the crop N/P requirement ratio, which leads to buildup of P in soils (Kingery et al., 1993). Understanding manure nutrient dynamics in soil with any particular crop is an important management practice for any farmer or producer to document accountability and to use manure resources optimally.

The objective of this study was to quantify input (broiler litter nutrients), output (plant uptake and soil residual content), and year-round dynamic/transformation of major plant nutrients in soil supplied with broiler litter. The results should help understand fate of nutrients from broiler litter to avoid misapplication of litter, which may lead to environmental problems, while maintaining optimum forage production compatible with litter application rates recommended for the Mississippi area.

MATERIALS AND METHODS

The study was conducted as part of a larger ongoing study on a farm near Mize, MS (31°48′ N, 89°36′ W), on a Savannah fine sandy loam (fine-loamy, siliceous, semiactive, thermic Typic Fragiudult). Plots were 2 by 6 m, separated by 1-m alleys and established on a site that has been receiving broiler litter (9.0–13.5 Mg ha^{-1} yr^{-1}) for more than 30 yr. Soil samples at 0- to 5- and 5- to 10-cm depths were collected from plots already established with common bermudagrass and hybrid bermudagrass cultivars Coastal and Tifton 85 (Burton, 1954; Burton et al., 1993) in a randomized complete block design replicated four times. Bermudagrass cultivars selected represent those which are available and frequently used by producers in the Southeast. In 2000, soil collection started in January and continued on a monthly basis until December. However, based on soil analyses from the Year 1, it was decided that in 2001, soil samples from the same plots be collected on a quarterly basis. Starting in May 2000, plots were harvested approximately every 6 wk. Forage yields were determined by cutting a 1- by 6-m swath at a 5-cm stubble height through the center of each plot with a sickle-bar mower. Subsamples were taken for the forage dry matter (DM) determination after samples were dried at 65°C for 48 h.

Abbreviations: DM, dry matter; ICP, inductively coupled plasma spectrophotometer.

Table 1. Initial soil chemical analyses (Mehlich 3, except for pH and N) and nutrient composition of broiler litter applied in 2000 and 2001.

	pH	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
		g kg^{-1}					mg kg^{-1}			
					Soil					
Depth (cm)										
0–5	6.2	1.59	0.74	0.30	1.09	0.13	29	283	160	35
5–10	6.4	0.56	0.35	0.17	0.59	0.09	10	231	192	7
					Litter					
2000										
May	7.7	34.9	22.5	29.6	30.1	6.1	687	837	631	416
July	7.8	32.7	19.8	28.7	29.8	6.5	632	795	703	456
2001										
May	7.4	32.5	20.8	29.1	30.9	6.4	541	1040	657	455
July	7.6	30.7	18.1	28.3	26.2	5.8	457	702	559	380

Broiler litter was hand-applied at 15.75 Mg ha^{-1} yr^{-1} (as-is basis) in mid-May (9.0 Mg ha^{-1}) and mid-July (6.75 Mg ha^{-1}) in both 2000 and 2001. Fresh broiler litter was obtained from a nearby broiler house at each application time. Subsamples of broiler litter were obtained for nutrient determination. The following chemical analyses were performed on bermudagrass DM, broiler litter, and soil samples, respectively. Soil pH was measured in a 1:1 soil/water ratio using 10 g of soil. Soil, plant, and litter total N and total C were measured by dry combustion using CE Elantech (Lakewood, NJ) CN analyzer. Soil samples (2 g) were extracted with 0.01 *M* KCl (1:10 soil/KCl ratio) (Mulvaney, 1996) and analyzed for nitrate (NO_3–N) and ammonium (NH_4–N) using a Dionex-500 Ion Chromatograph (Dionex Corp., Sunnyvale, CA). Soil samples were extracted with Mehlich-3 soil extractant (Mehlich, 1984), 1:10 soil/extractant using 2 g of soil; shaken for 30 min; and filtered through Whatman Fisher brand filter paper (2V) for the determination of P and metals using a Thermo Jarrell-Ash Inductively Coupled Plasma Spectrophotometer (ICP) (Thermo Jarrell-Ash, Franklin, MA). Soil samples were also extracted with deionized water (1:10 soil/water ratio) for water extractable P. Soil total P was determined by digesting 0.50 g of air-dried soil using sulfuric acid, hydrogen peroxide, and hydrofluoric acid (Kuo, 1996) followed by the determination of P using the ICP. Approximately 0.8 g of plant tissue was ashed in a muffle furnace (Thermolyne Corp. 30400, Dubuque, IA) at 500°C for 4 h. Ash was dissolved first in 1.0 mL of 6 *M* HCl for 1 h, followed by 50 mL of a double-acid solution of 0.025 *M* H_2SO_4 and 0.05 *M* HCl, and the mixture was allowed to stand for another hour before filtration (Southern Coop. Ser., 1983). The ashed samples were used for the following analyses: total P, K, Ca, Mg, Cu, Fe, Mn, and Zn using the ICP. Initial soil chemical properties and total broiler litter nutrient content are presented in Table 1.

Data were analyzed using the PROC GLM procedure of SAS (SAS Inst., 1998). Since interaction of year × cultivar was not significant, DM yield and nutrient uptake are presented as average of 2 yr (2000 and 2001). Mean comparison was done using Fisher's protected LSD ($P < 0.05$).

Table 2. Annual dry matter (DM) yield and uptake of selected plant nutrients by bermudagrass cultivars (mean of 2 yr).

Bermudagrass cultivar	DM	N	P	K	Zn	Cu
	kg ha^{-1}					
Coastal	16 948a	313a	46b	366b	0.65b	0.12a
Common	11 238b	249b	39c	238c	0.44c	0.12a
Tifton 85	18 772a	344a	58a	471a	1.10a	0.13a
LSD†	1 842	45	6	54	0.01	0.02

† The least significant difference (LSD 0.05) compares each column.

RESULTS AND DISCUSSION

Nutrient Inputs

Table 1 shows soil background nutrient content for 0- to 5- and 5- to 10-cm depths. Due to long-term surface application of broiler litter before the establishment of our experimental plots, most of the nutrients, particularly P (740 mg kg^{-1}) and N (1.59 g kg^{-1}), were high at the 0- to 5-cm soil depth. Based on calculations from information in Table 1 and litter application rate of 15.75 Mg ha^{-1} yr^{-1} (7 tons acre^{-1}), the following quantities of N, P, and K were applied in 2000 and 2001: N, 535 and 408 kg ha^{-1}; P, 337 and 319 kg ha^{-1}; and K, 374 and 453 kg ha^{-1}, respectively. These values represent total quantities of N, P, and K in broiler litter that was applied for 2 yr. Based on the assumption that half of the total supplied nutrients will become available for plant uptake in the first year, there were enough nutrients for maximum bermudagrass hay production (Brinson et al., 1994; Gordillo and Cabrera, 1997; Eghball and Power, 1999). Since broiler litter application was based on N requirement of bermudagrass, more P was applied than the amount required for maximum plant growth. Other mineral nutrients such as Ca, Mg, Cu, Fe, Mn, and Zn that were supplied by broiler litter were either adequate or more than required by bermudagrass (Table 1).

Dry Matter and Nutrient Uptake

Hybrid bermudagrass cultivars Coastal and Tifton 85 produced significantly greater annual DM yield than common bermudagrass. However, Tifton 85's mean DM was numerically greater than Coastal by 1824 kg ha^{-1} (Table 2). Mean DM yields of hybrid cultivars and common bermudagrass were quite high at 17 860 and 11 238 kg ha^{-1} (approximately 8 and 5 tons acre^{-1}), respectively.

Annual nutrient uptake was calculated as the product of DM yield and the forage nutrient concentration at each harvest and then summed over all harvests for the yearly basis. Nitrogen uptake followed the same trend as DM yield, with Coastal and Tifton 85 removing significantly greater N than common bermudagrass. Tifton 85 removed significantly greater P, K, Zn, and Cu than Coastal and common bermudagrass (Table 2). Tifton 85 removed averages of 344, 58, and 472 kg ha^{-1} N, P, and K, respectively, from soil while the quantities of these nutrients supplied by broiler litter application

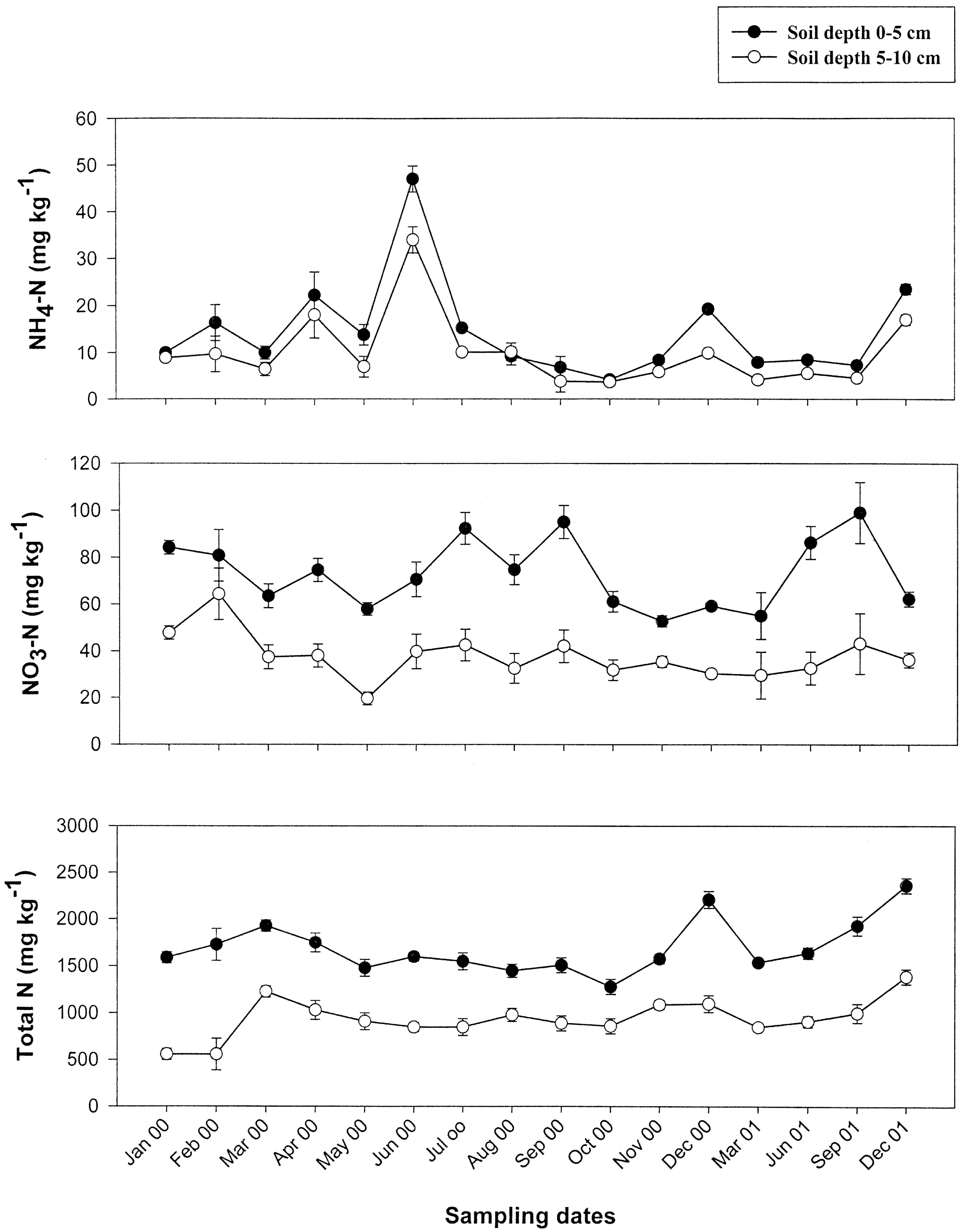

Fig. 1. Average concentrations of total N, NO_3–N, and NH_4–N in 0- to 5- and 5- to 10-cm soil depths for 2000 and 2001.

were 471, 328, and 414 kg ha^{-1} (mean of 2 yr), respectively. Therefore, annual removal efficiency of N, P, and K by Tifton 85 (most efficient cultivar among the three) relative to total application was 73, 18, and 114%, respectively. It is obvious that fertilization of forages by broiler litter to meet N need of the forage may result in overapplication of P, which in the long term may cause P buildup in soil and potential for environmental problems, as previously reported by others (Sims, 1995). In contrast to P, all bermudagrass cultivars were very efficient in K removal, particularly Tifton 85. It has been reported that hybrid bermudagrass cultivars remove high quantities of K (Day and Parker, 1985). It should also be noted that in spite of small P uptake from soil by bermudagrass, removal of litter-derived P in the form of hay would curtail P buildup in soil for the long term (Sims and Wolf, 1994; Brink et al., 2001).

Based on calculations from Table 1, the quantities of Cu, Fe, Mn, and Zn applied by broiler litter (mean of 2 yr) were 9, 13, 10, and 7 kg ha^{-1}, respectively. Some of the micronutrients, particularly Cu and Zn, are normally added to broiler feed as dietary supplements to improve weight gain, prevent diseases, and control the growth of fungus in the feed (Han et al., 2000). Micronutrients removed by bermudagrass cultivars tested in this study were very low (Table 2) relative to quantities supplied by litter application. However, concentrations of these metals in soils are usually low; hence, only a very long-term broiler litter application may cause high accumulation in soils (Wood and Hattey, 1995).

Soil Nutrient Dynamics

Total N content for 0- to 5- and 5- to 10-cm soil depths was 1.50 and 0.50 g kg^{-1}, respectively, in January 2000 (Fig. 1). High N concentration in the soil surface was due to surface application of broiler litter without any incorporation. Total N decreased slightly during high demand for N by bermudagrass (June to October) when optimum environmental conditions such as soil moisture also existed for bermudagrass growth. Total N at both soil depths was much greater in December 2001 relative to January 2000, the start of this experiment. The NH_4–N and NO_3–N fluctuations were drastic, particularly right after litter applications in mid-May and July (Fig. 1). The NO_3–N concentration in soil surface was greater than NH_4–N at all sampling dates. Even though NH_4–N

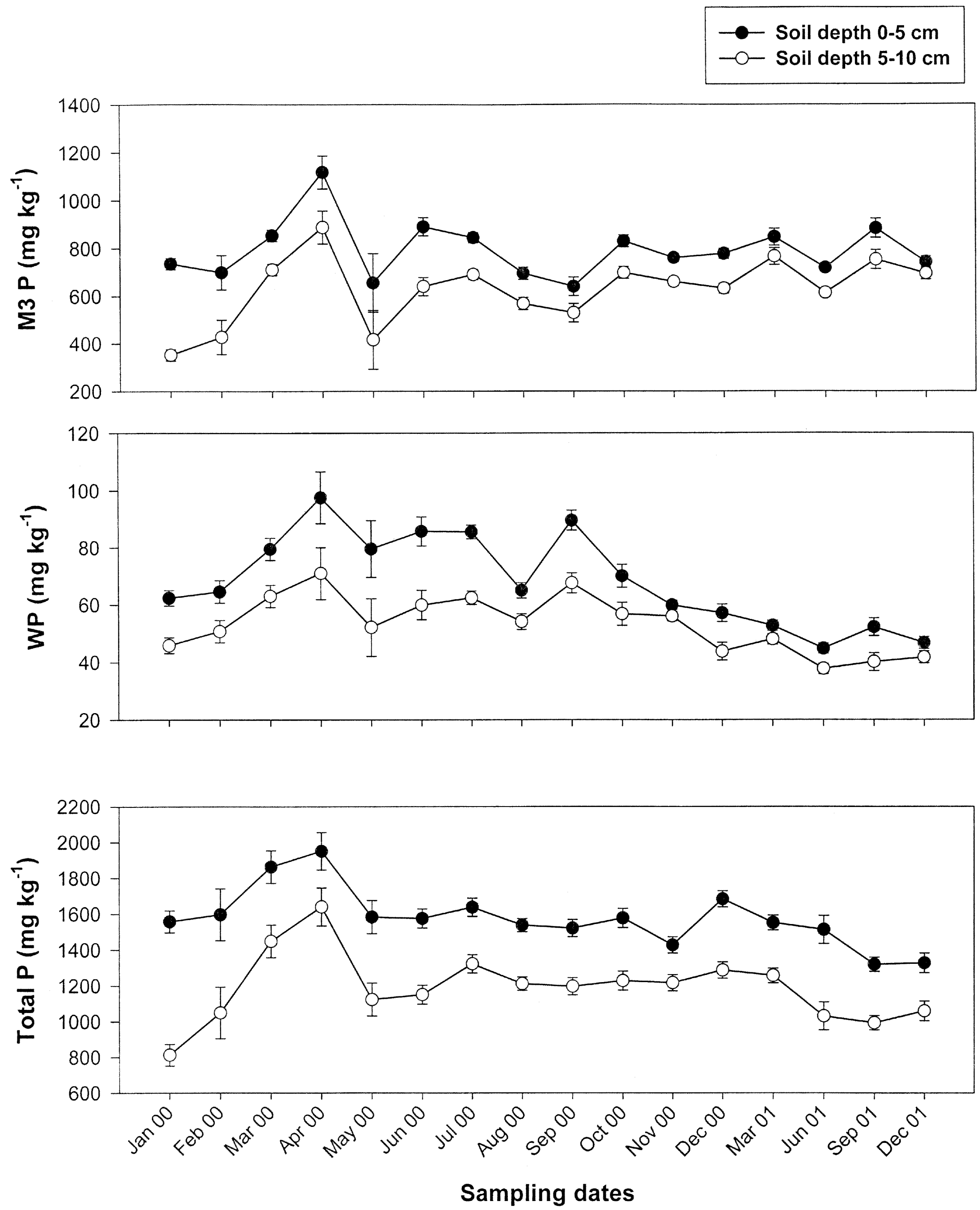

Fig. 2. Average concentrations of total P, water extractable P (WP), and Mehlich-3 P (M3 P) in 0- to 5- and 5- to 10-cm soil depths for 2000 and 2001.

decreased by late summer and early fall, the NO_3–N stayed high, probably due to continuous nitrification in the topsoil where there is generally enough free oxygen. Therefore, proper litter application practices need to be exercised to prevent the seasonal buildup of NO_3–N in the soil surface, which may be leached and create environmental problems (Nyakatawa et al., 2001). During late fall and winter, organic N was greater than in the summer because bermudagrass is normally dormant during winter months and there is no demand for N (Fig. 1). There were increasing trends in all forms of P for both soil depths from January 2000 to April 2000, which may be due to residual effects related to the previous-year activities (Fig. 2). Both total P and Mehlich-3 extractable P concentrations increased from first sampling (January 2000) to last sampling (December 2001) dates. Increase was mainly in the 5- to 10-cm soil depth, which reflects a slight buildup and leaching of P during the 2-yr span. The P buildup in soil with long-term litter application, on the basis of N requirement of the crop, is also reported by many other investigators (Sharpley et al., 1994; Eghball et al., 1996).

Total soil C increased from approximately 11 g kg^{-1} in January 2000 to 18 g kg^{-1} by December 2001. The increase in soil C due to manure application is also reported by other studies (Rasmussen et al., 1998; Nyakatawa et al., 2001). Soil pH fluctuated from 6.0 to 6.6 from January 2000 to March 2001; however, it decreased unexpectedly to 5.6 by December 2001 (Table 3). Other studies have reported that manure application increases soil pH (Warren and Fonteno, 1993; Cooper and Warman, 1997; Eghball and Power, 1999). However, soil pH has also been shown to decline in some manure-amended soils (Chang et al., 1990; King et al., 1990); hence, the effect of manure on soil pH may vary and depend mainly on the manure source and soil characteristics.

Tables 3 and 4 show Ca, Mg, K, Cu, Fe, Mn, and Zn concentrations in soil for 2000 and 2001. Calcium concentration was greater during spring and summer compared with fall and winter months. Magnesium and K concentrations in the soil did not change substantially from month to month or season to season. Concentrations of micronutrients Cu, Fe, Mn, and Zn in soil varied throughout the year with greater concentrations during late spring and summer. This fluctuation may have been influenced by soil moisture and temperature at the time of soil sampling. Soil test concentrations for these micronutrients were within the sufficiency ranges listed for Coastal bermudagrass, except for Cu, for which the soil concentration was greater than plant tissue sufficiency range (4–20 mg kg^{-1}) (Southern Coop. Ser., 2000).

Table 3. Soil pH, total C (TC), Ca, Mg, and K content at different sampling times in 2000 and 2001.

Sampling dates	Soil depth	pH	TC	Ca	Mg	K
	cm		g/kg			
Jan. 2000	0–10	6.2†	11.4 ± 1.4	0.84 ± 0.3	0.11 ± 0.0	0.24 ± 0.1
Feb. 2000	0–10	6.3	10.9 ± 0.9	0.88 ± 0.3	0.13 ± 0.1	0.32 ± 0.3
Mar. 2000	0–10	6.2	15.3 ± 1.3	1.24 ± 0.3	0.15 ± 0.0	0.28 ± 0.0
Apr. 2000	0–10	6.2	15.8 ± 0.9	1.65 ± 0.5	0.22 ± 0.1	0.31 ± 0.1
May 2000	0–10	6.0	13.5 ± 1.0	1.34 ± 0.4	0.17 ± 0.1	0.26 ± 0.0
June 2000	0–10	6.2	14.7 ± 0.6	1.63 ± 0.5	0.21 ± 0.1	0.32 ± 0.1
July 2000	0–10	6.0	15.4 ± 1.0	1.13 ± 0.2	0.14 ± 0.0	0.31 ± 0.1
Aug. 2000	0–10	6.3	13.4 ± 0.6	1.10 ± 0.2	0.14 ± 0.0	0.30 ± 0.1
Sept. 2000	0–10	6.6	14.5 ± 0.7	0.90 ± 0.3	0.11 ± 0.0	0.26 ± 0.1
Oct. 2000	0–10	6.2	13.6 ± 1.0	1.11 ± 0.2	0.15 ± 0.0	0.27 ± 0.1
Nov. 2000	0–10	6.3	15.0 ± 0.6	1.05 ± 0.2	0.12 ± 0.0	0.28 ± 0.1
Dec. 2000	0–10	6.6	16.8 ± 1.9	1.29 ± 0.4	0.15 ± 0.0	0.27 ± 0.1
Mar. 2001	0–10	6.2	13.5 ± 0.4	1.04 ± 0.2	0.12 ± 0.0	0.25 ± 0.1
June 2001	0–10	5.6	14.5 ± 0.7	1.09 ± 0.2	0.11 ± 0.0	0.29 ± 0.1
Sept. 2001	0–10	5.5	14.6 ± 0.8	1.26 ± 0.3	0.16 ± 0.1	0.33 ± 0.1
Dec. 2001	0–10	5.6	17.9 ± 0.7	1.36 ± 0.3	0.15 ± 0.0	0.25 ± 0.0

† Data points are averages of 24 values, ±standard deviations, and extracted by Mehlich 3.

CONCLUSIONS

This study was designed to evaluate the nutrient dynamics in soil throughout the year when broiler litter is the sole source of nutrients. Determination of critical nutrient balances in soil with regard to environmental implications requires knowledge of nutrient input credited to manure, nutrient removal by plants, and losses that may occur within manure management and crop production systems. Broiler litter is rich in P and some micronutrients relative to the quantities required by plants. As indicated by results of this study, P, Cu, and Zn, and potentially Mn and Fe, may accumulate in soil receiving long-term broiler litter, unless continuous soil

Table 4. Soil concentrations of Cu, Fe, Mn, and Zn at different sampling times in 2000 and 2001.

Sampling dates	Soil depth	Cu	Fe	Mn	Zn
	cm	mg/kg			
Jan. 2000	0–10	19.8 ± 7.2†	257.7 ± 36.3	176.5 ± 30.5	21.2 ± 15.3
Feb. 2000	0–10	20.7 ± 7.3	236.7 ± 42.3	172.6 ± 29.6	26.8 ± 18.2
Mar. 2000	0–10	32.5 ± 6.9	287.1 ± 10.4	153.4 ± 16.1	40.9 ± 11.1
Apr. 2000	0–10	43.6 ± 13.2	511.8 ± 70.5	284.5 ± 54.7	57.6 ± 19.5
May 2000	0–10	36.3 ± 8.6	459.2 ± 43.1	250.9 ± 46.4	46.6 ± 16.8
June 2000	0–10	50.3 ± 13.6	483.2 ± 29.8	260.6 ± 32.8	56.4 ± 19.3
July 2000	0–10	38.2 ± 7.6	321.4 ± 27.2	160.6 ± 23.8	43.0 ± 12.6
Aug. 2000	0–10	21.9 ± 6.9	499.5 ± 66.6	239.4 ± 41.1	37.3 ± 10.4
Sept. 2000	0–10	27.3 ± 7.7	301.9 ± 31.3	132.9 ± 20.2	31.7 ± 12.5
Oct. 2000	0–10	34.7 ± 7.7	423.5 ± 26.2	172.4 ± 21.9	35.7 ± 10.7
Nov. 2000	0–10	33.3 ± 7.4	372.4 ± 23.3	156.4 ± 25.8	34.9 ± 10.6
Dec. 2000	0–10	25.8 ± 8.9	118.8 ± 1.6	182.2 ± 30.8	39.6 ± 14.2
Mar. 2001	0–10	31.0 ± 6.3	421.0 ± 46.8	145.4 ± 17.9	41.0 ± 12.1
June 2001	0–10	31.3 ± 6.2	109.6 ± 3.0	125.3 ± 12.5	32.6 ± 10.1
Sept. 2001	0–10	37.2 ± 7.2	302.8 ± 36.7	108.1 ± 14.5	47.2 ± 15.8
Dec. 2001	0–10	32.8 ± 6.1	220.3 ± 14.9	85.0 ± 11.9	46.0 ± 14.0

† Data points are averages of 24 values, ±standard deviations, and extracted by Mehlich 3.

test monitoring, proper litter application rate, and maximization of crop removal are exercised. Therefore, budgeting of P may be required in areas where soil P concentration increases to the level of concern.

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